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REVIEW/MISE AU POINT

Which biomechanical models are currently used in standing posture analysis?

Quels sont les modèles biomécaniques utilisés actuellement en analyse de la posture debout ?

A. Crétual[a,b,*]

[a] *M2S lab (Mouvement Sport Santé), University Rennes 2 — ENS Rennes — UEB, avenue Robert-Schuman, campus de Ker Lann, 35170 Bruz, France*
[b] *MimeTIC team, INRIA Rennes, campus universitaire de Beaulieu, 35042 Rennes, France*

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Summary In 1995, David Winter concluded that postural analysis of upright stance was often restricted to studying the trajectory of the center of pressure (CoP). However, postural control means regulation of the center of mass (CoM) with respect to CoP. As CoM is only accessible by using a biomechanical model of the human body, the present article proposes to determine which models are actually used in postural analysis, twenty years after Winter's observation. To do so, a selection of 252 representative articles dealing with upright posture and published during the four last years has been checked. It appears that the CoP model largely remains the most common one (accounting for nearly two thirds of the selection). Other models, CoP/CoM and segmental models (with one, two or more segments) are much less used. The choice of the model does not appear to be guided by the population studied. Conversely, while some confusion remains between postural control and the associated concepts of stability or strategy, this choice is better justified for real methodological concerns when dealing with such high-level parameters. Finally, the computation of the CoM continues to be a limitation in achieving a more complete postural analysis. This unfortunately implies that the model is chosen for technological reasons in many cases (choice being a euphemism here). Some effort still has to be made so that bioengineering developments allow us to go beyond this limit.

* Correspondence. M2S lab (Mouvement Sport Santé), University Rennes 2 — ENS Rennes — UEB, avenue Robert-Schuman, campus de Ker Lann, 35170 Bruz, France.
E-mail address: armel.cretual@univ-rennes2.fr

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MOTS CLÉS
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Les modèles segmentaires ;
Le contrôle postural

Résumé En 1995, David Winter faisait remarquer que l'analyse de la posture quasi statique debout était souvent réduite à l'étude de la trajectoire du centre de pression (CdP). Pourtant, le contrôle postural consiste en la régulation du centre de masse (CdM) par rapport au CdP. Comme le CdM ne peut être estimé qu'à travers l'utilisation d'un modèle du corps humain, cet article propose de déterminer quels sont les modèles utilisés en analyse posturale vingt ans après l'observation faite par Winter. Pour cela, une sélection représentative de 252 articles traitant de la posture debout et publié lors des quatre dernières années a été étudiée. Il apparaît que le modèle n'utilisant que le CdP reste largement majoritaire (près des deux tiers de la sélection). Les autres modèles, CdP/CdM ou segmentaires (avec un, deux ou plus de segments) sont nettement moins utilisés. Ce choix du modèle ne semble pas guidé par le type de population étudiée. À l'inverse, même s'il existe toujours des confusions entre le contrôle postural et des concepts qui lui sont associés tels que stabilité ou stratégie, le choix du modèle est mieux justifié d'un point de vue méthodologique lorsqu'il s'agit d'évaluer ces paramètres de plus haut niveau. Enfin, le calcul du CdM continue à être une limite pour parvenir à une analyse posturale plus complète. Cela implique que le modèle est en réalité souvent choisi pour des questions technologiques (choix étant alors un euphémisme). Des efforts restent donc à fournir pour que les développements en bio-ingénierie permettent de dépasser cette limite.

Introduction

The maintenance of quiet standing in humans has been the subject of numerous publications over many years, from the beginning of the 20th century onwards. From a mechanical point of view, this task is quite a simple one to study. Only two forces are involved: the weight and the ground reaction force. Their points of application are respectively the center of gravity (CoG), which is identical to the center of mass (CoM), and the center of pressure (CoP). As the weight of a given subject remains constant, only the evaluation of the ground reaction force is needed, from the forces point of view. Nevertheless, as explained by Stoffregen and Riccio in 1988 [84] and recalled by Winter in his consistently cited review article on human balance [90], this situation is not stable, since any horizontal displacement of the CoM with respect to the CoP will create a torque that will increase this displacement and therefore lead to falling if nothing is done to counterbalance it. Thus, owing to this mechanically unstable situation, quiet standing needs a permanent control of CoP and CoM relative positions, such that the distance between CoP and the projection of CoM onto the horizontal plane remains on average equal to zero. The position of the CoP can be modified through the distribution of plantar pressures; whereas CoM is modified by displacements of one body part relative to others. Let us denote that this zero-mean distance is only a necessary condition. Due to a restricted margin of stability, the length of the temporal interval during which this zero-mean condition must be respected is actually very short. These spatial and temporal margins of stability are indeed narrower than the one identified by Hof et al. [49] as they consider the excursion of the CoP or the CoM independently one from the other with respect to the convex hull of the feet (or possibly one single foot).

A complete kinetic study of human standing posture would therefore need to consider both CoM and CoP. This implies measuring or estimating these through computation from indirect measurement. It is well known that none of them is an anatomical point. Position of the CoP is quite easily accessible through measurements provided by pressure mapping sensors or, more usually in posturography, through ground reaction force and torques obtained from a forceplate. The CoM position is a bit more complex to estimate. It has to be computed by taking into account relative motions of each part of the body in relation to each other, proportionally to their masses. An ideal measurement would be some kind of real-time MRI giving the position of any voxel of the body as well as its composition, to be able to retrieve its mass. Unfortunately, such a device does not as yet exist. The computation of CoM position obviously needs to rely on a simplification of body representation. The most common way to do so in biomechanics is to consider the body as a set of rigid segments (first approximation) that are articulated one with respect to the previous one in the kinematics chain through perfect joints (second approximation) [92]. Consequently, studying a person's posture or movement (succession of postures) essentially means providing the joint angles. With the hypothesis of rigid segments, it follows that the center of mass of each segment is stationary with respect to its two extremities. Therefore, knowing the mass of all body segments allows computation of the global CoM as a weighted sum of each segment's center of mass. Even if some methods are proposed to have access to individual values of inertia parameters [25], the most current process is based on anthropometric tables [29]. This computation has been validated, comparing CoM acceleration to what can be obtained from forceplate measurement [59]. Even if the widely accepted ISB recommendations for the joint angles computation of joint angles for lower [93] and upper body [94] are still debated, and some improvements are regularly proposed (for example for the shoulder [53] or the shank [22]), the principle of the articulated rigid bodies model is never questioned.

Anyone interested in biomechanical analysis of human motion agrees that the very usual 14-segments model can be modified depending on the movement that is actually studied, as recalled by Winter in his reference book [91].